Overview of Propagation Studies at NASA Glenn Research Center

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Outline

- Propagation Program Objectives
- Program History
- Summary of Current Propagation Campaigns
- Modeling Activities
- GRC Propagation Laboratories
- Future Plans

Program Objectives

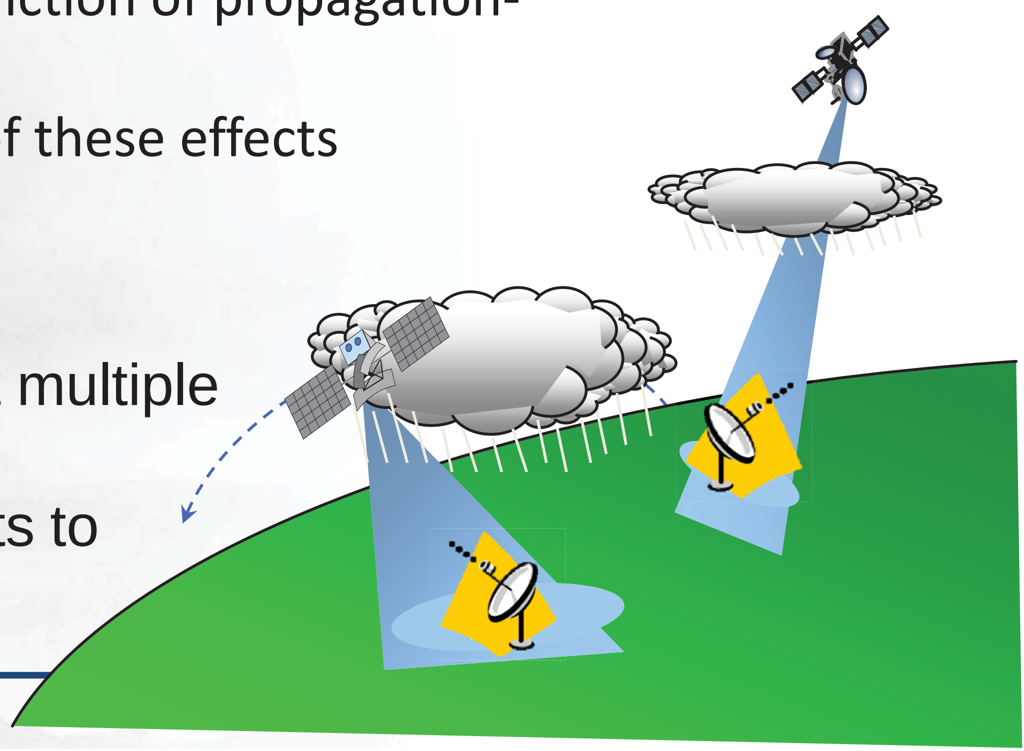
As NASA and the Nation move toward operations at Ka-band frequencies and above, it is desirable to characterize the site-dependent atmospheric propagation effects to manage expectations for system performance and develop improved systems at current and future potential operational sites.

Objectives:

- To provide a good understanding of RF propagation effects
- To develop or validate models for the prediction of propagation-related effects
- To develop techniques for the mitigation of these effects

How to accomplish the objectives:

- By making long-term measurements at multiple sites and analyzing the collected data
- A timely and full dissemination of results to users of propagation data



Program History

Advanced Component Technology Satellite (ACTS)

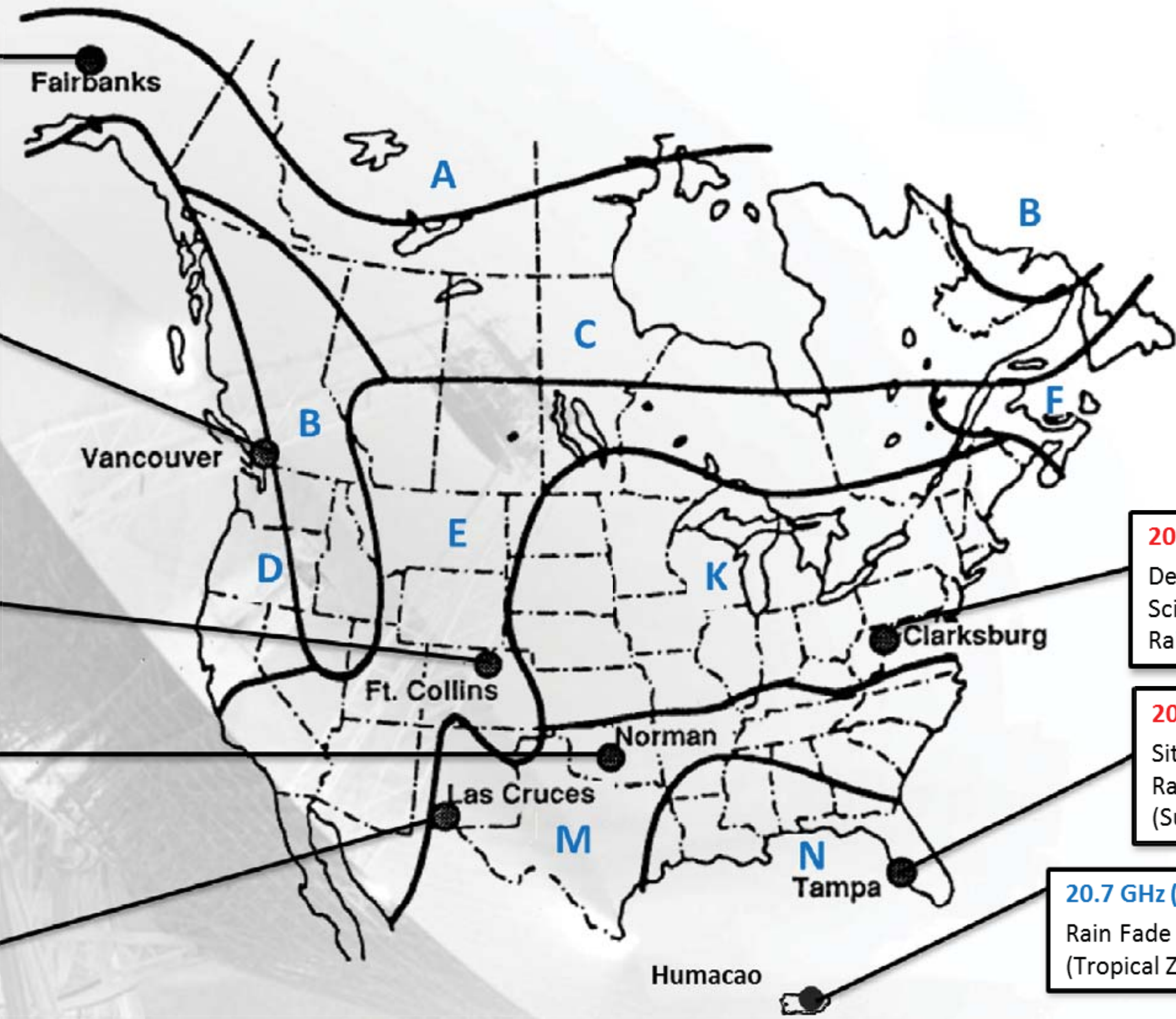
20.2/27.5 GHz (K/Ka)
Gaseous Absorption
Scintillation
Rain Fade

20.2/27.5 GHz (K/Ka)
Gaseous Absorption
Scintillation
Rain Fade

20.2/27.5 GHz (K/Ka)
Rain Fade
Snow Fade
Depolarization

20.2/27.5 GHz (K/Ka)
Scintillation
Rain Fade

20.2/27.5 GHz (K/Ka)
Gaseous Absorption
Scintillation
Rain Fade



20.2/27.5 GHz (K/Ka)
Depolarization
Scintillation
Rain Fade

20.2/27.5 GHz (K/Ka)
Site Diversity
Rain Fade
(Subtropical Zone)

20.7 GHz (K)
Rain Fade
(Tropical Zone)

GRC possesses over 35+ station years of Ka-band propagation data collected through the Advanced Communications Technology Satellite (ACTS) program.

Overview of Current Efforts

Propagation Terminal Development

ACTS Propagation Terminal

Operational Frequency: 20.7/27.5 GHz
Dynamic Range: 20 dB
Sampling Rate: 1 Hz/10 Hz
Resolution: <0.3 dB rms accuracy

Hardware-based FFT Receiver

Goldstone Interferometer

Operational Frequency: 20.2 GHz
Dynamic Range: 30 dB
Sampling Rate: 1 Hz
Resolution: <0.1 dB rms accuracy

Software-based FFT Receiver

White Sands/Guam Terminal

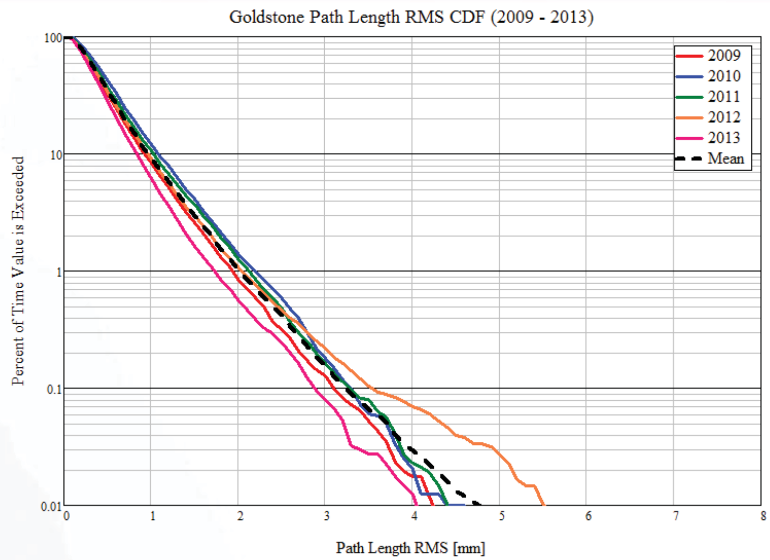
Operational Frequency: 20.2 GHz
Dynamic Range: 40 dB
Sampling Rate: 1 Hz/10 Hz
Resolution: <0.1 dB rms accuracy

Software-based Frequency Estimation Receiver

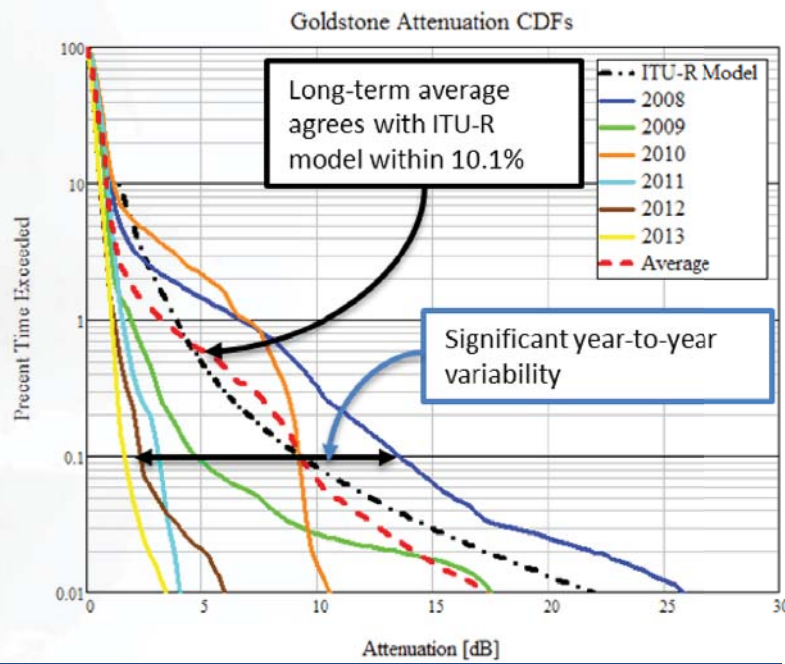
Throughout propagation campaigns, ground station hardware has undergone evolutionary improvements in performance and autonomous operation procedures.

SITE SUMMARIES

Goldstone Campaign
Atmospheric Phase Turbulence Studies



Instrument : Two-Element Ka-Band Interferometer (20.2 GHz)
Data Collection Started : May 2007
Data Collection Completed: September 2012 (but ongoing)
Total Number of Months : 88 (7.3 Years)



Collected 7+ years of atmospheric attenuation measurements
Collected 7+ years of phase turbulence measurements
Measurements have been validated with interferometer at secondary location at DSN Complex

White Sands Campaign

Atmospheric Phase Turbulence Studies

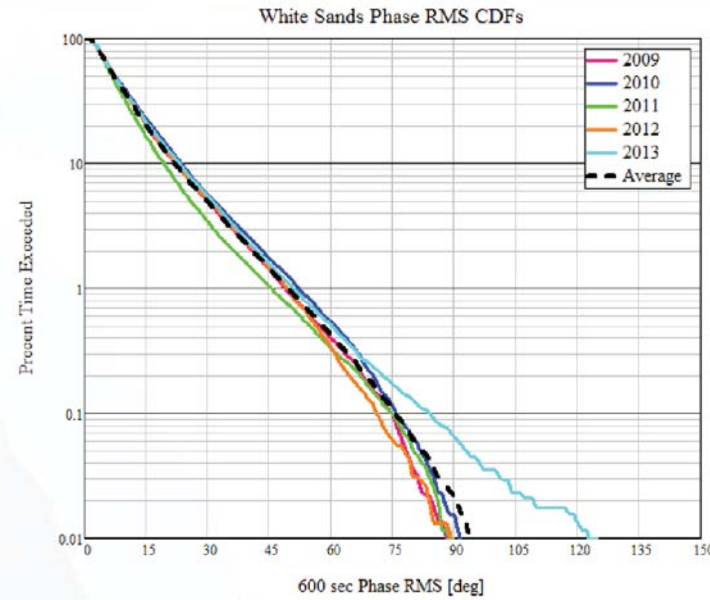
Instruments : Two-Element Ka-Band Interferometer (20.2 GHz)
Microwave Profiling Radiometer (22-60 GHz)
W/V-band Radiometer (82/72 GHz)

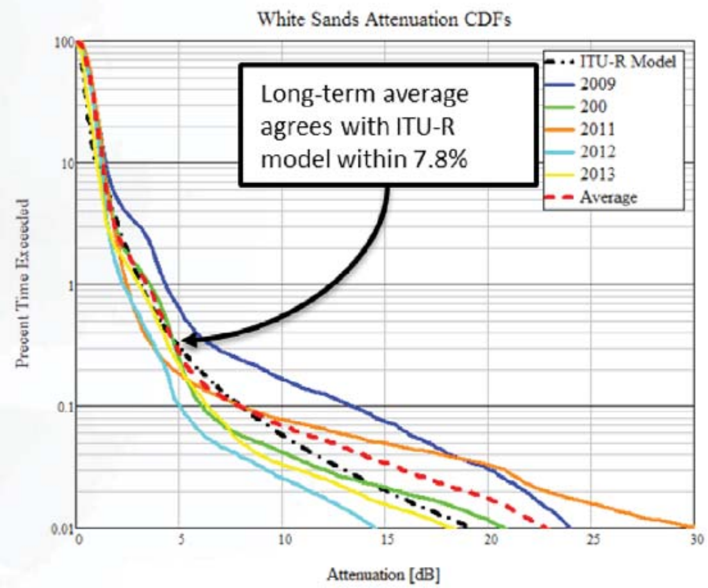
Data Collection Started : February 2009

Total Number of Months : 68 (5.7 Years)

Collected 5+ years of atmospheric attenuation measurements

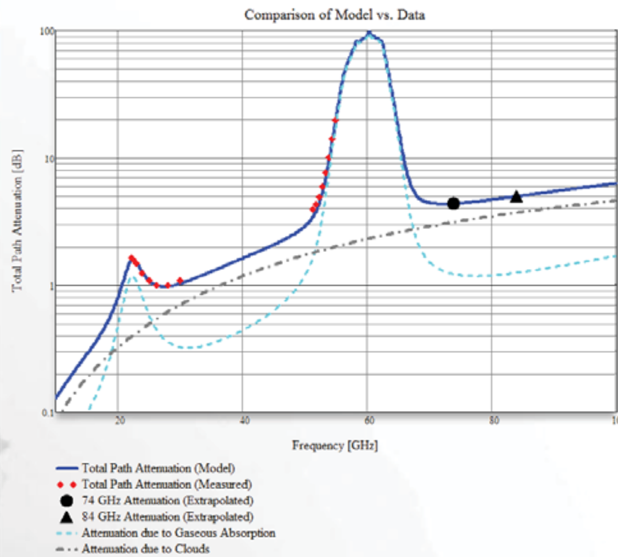
Collected 5+ years of phase turbulence measurements

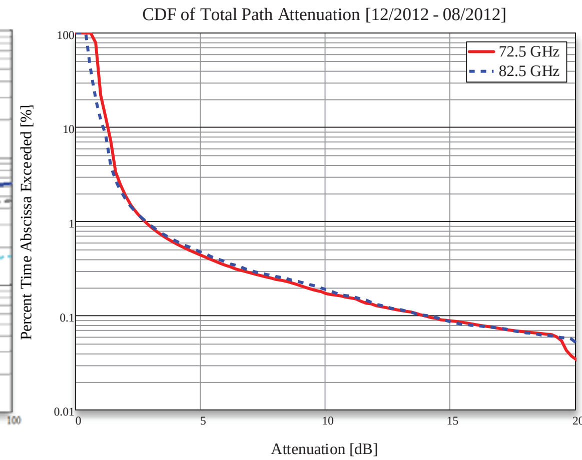




White Sands Campaign

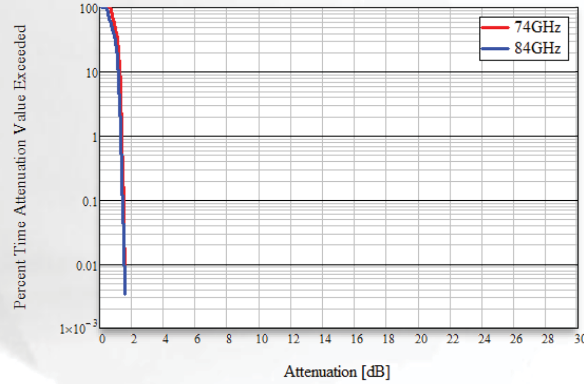
Millimeter Wave Precursor Studies



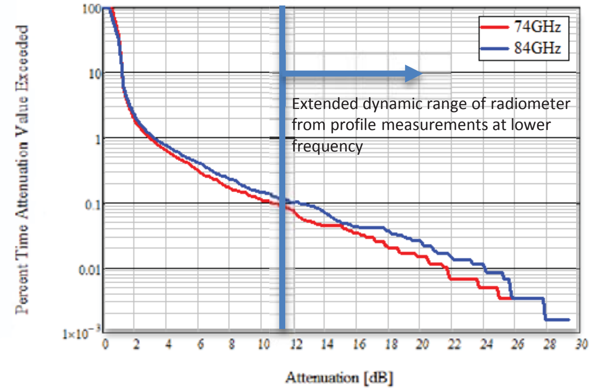


Instrument : Profiler, W/V-Band Radiometer
Data Collection Started : December 2012
Total Number of Months : 24 (2 years)

CDF of Gaseous Attenuation



CDF of Cloud Attenuation

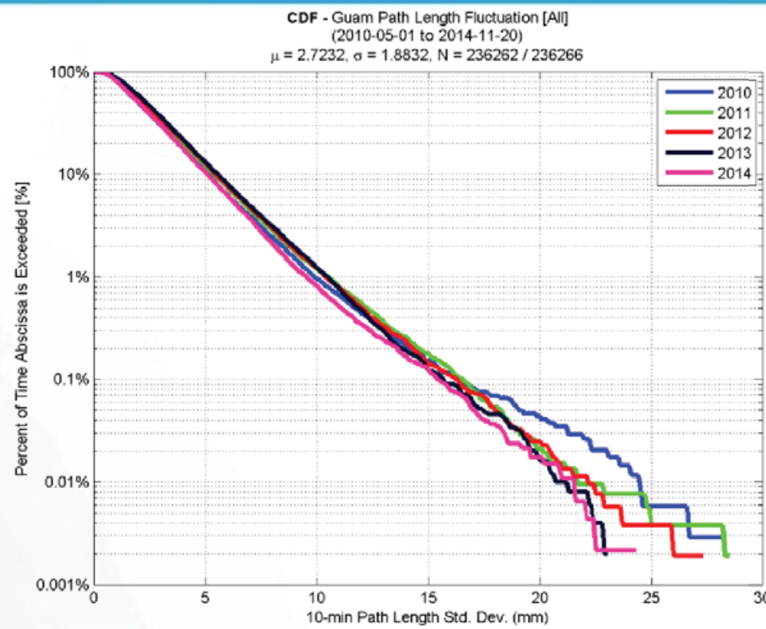


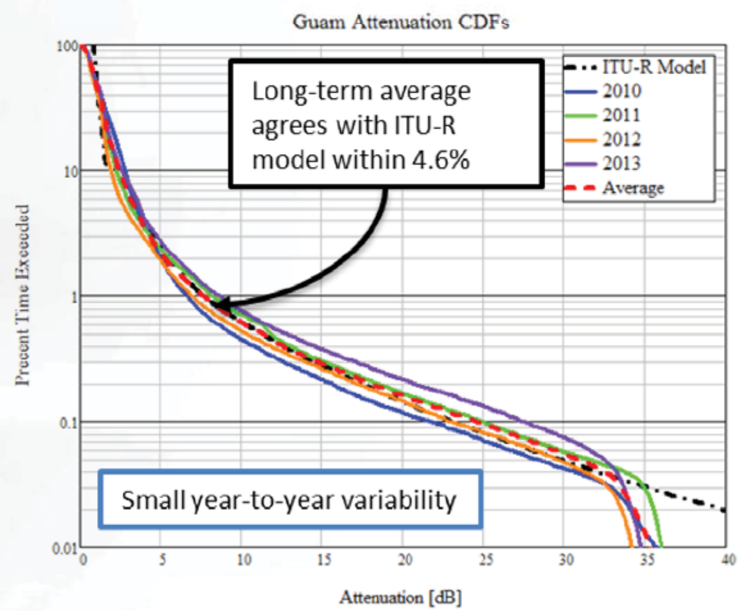
Collected 2+ years of W/V-band gaseous and cloud attenuation measurements
Extrapolation of profiler measurements/absorption models to W/V-band validated with direct W/V-band radiometer measurements

Guam Campaign
Propagation Studies in the Tropics

Instrument : Two-Element Ka-Band Interferometer (20.7 GHz)
Data Collection Started : May 2010
Total Number of Months : 54 (4.5 Years)

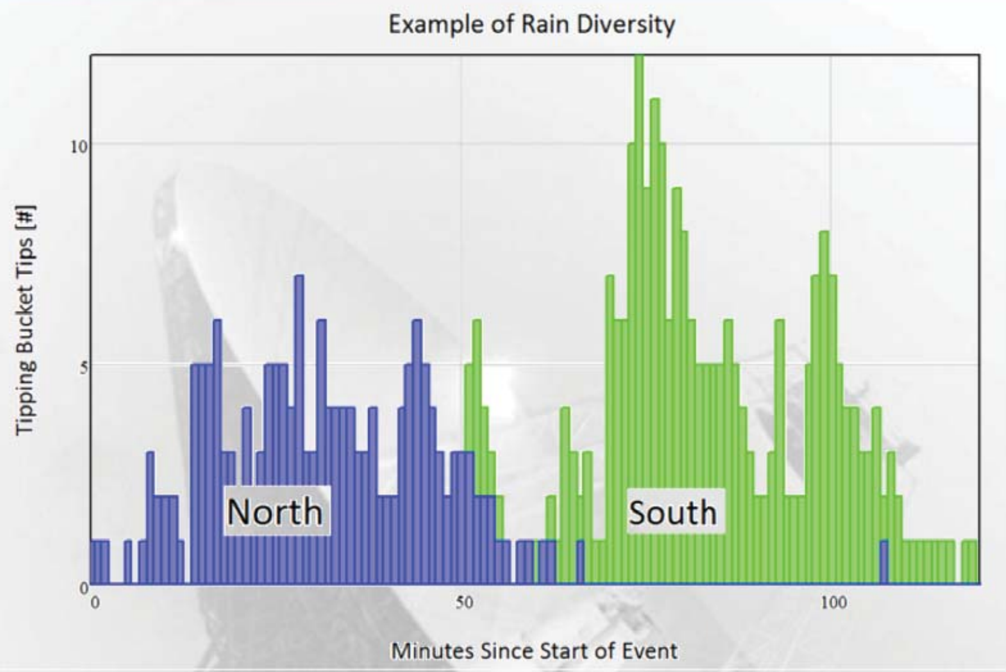
Collected 4+ years of atmospheric attenuation measurements
Collected 4+ years of phase turbulence measurements
Collected 4+ years of site diversity measurements

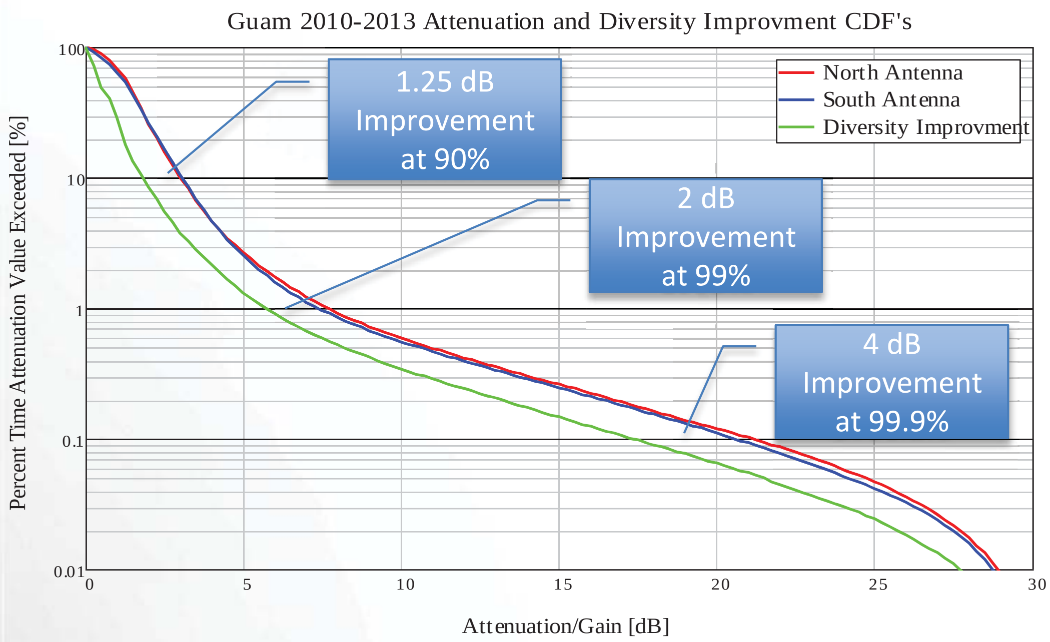




Guam Campaign

Site Diversity Analysis

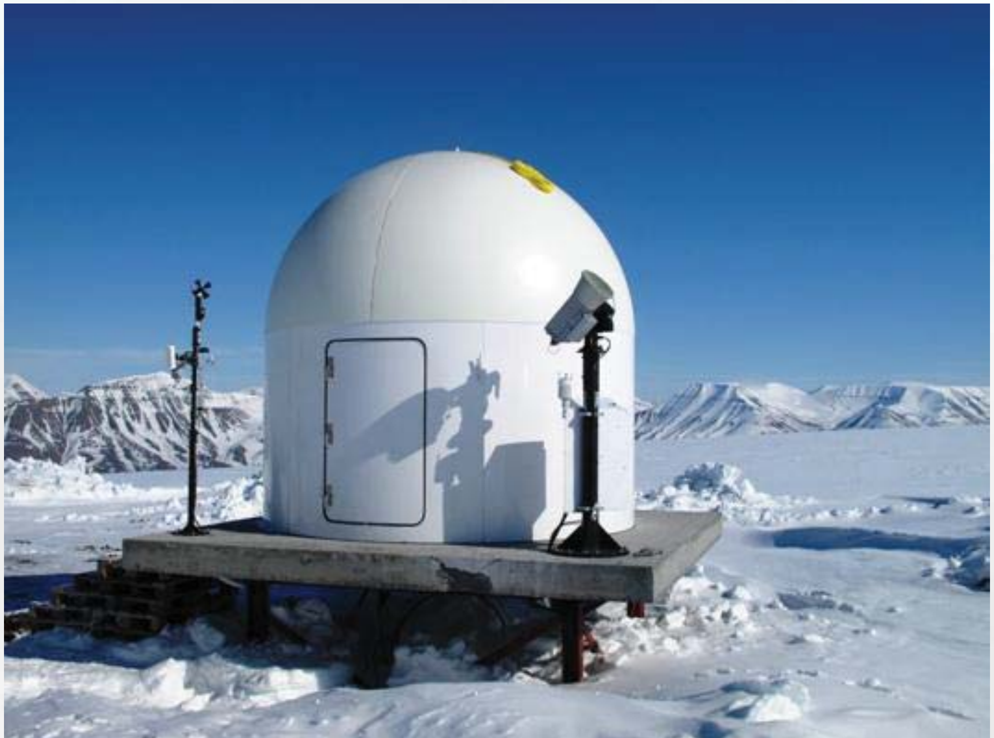




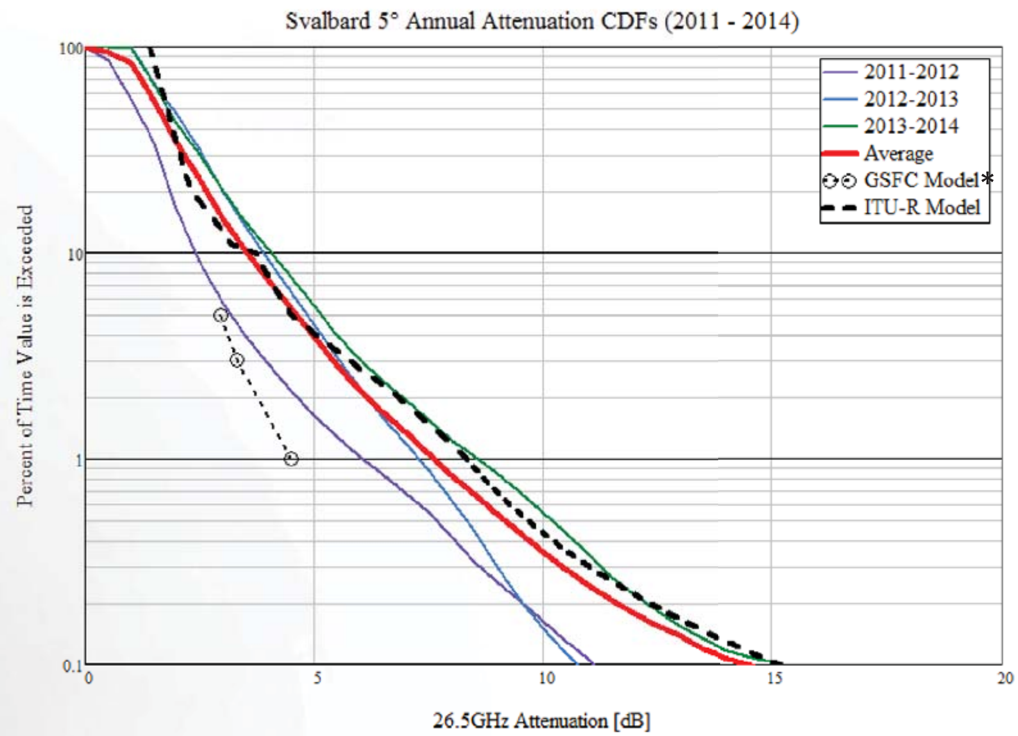
- Compact, highly convective rainfall in Guam has shown evidence of rain diversity over short (600-m) antenna separation distances.
- Guam site diversity study indicates that meaningful diversity gain is possible within short baseline separation distances (<20 km) and is sufficient to overcome rain attenuation
- Analysis results lays foundation for modeling of short baseline site diversity, which his currently lacking
- **IMPACT: Conclude that high availability Ka-band operations in a tropical environment is possible utilizing short baseline site diversity**

Svalbard Campaign

Propagation Studies in the Polar Climate



Instrument : Ka-Band Radiometer (26.5 GHz)
Data Collection Started : May 2011
Total Number of Months : 42 (3.5 Years)

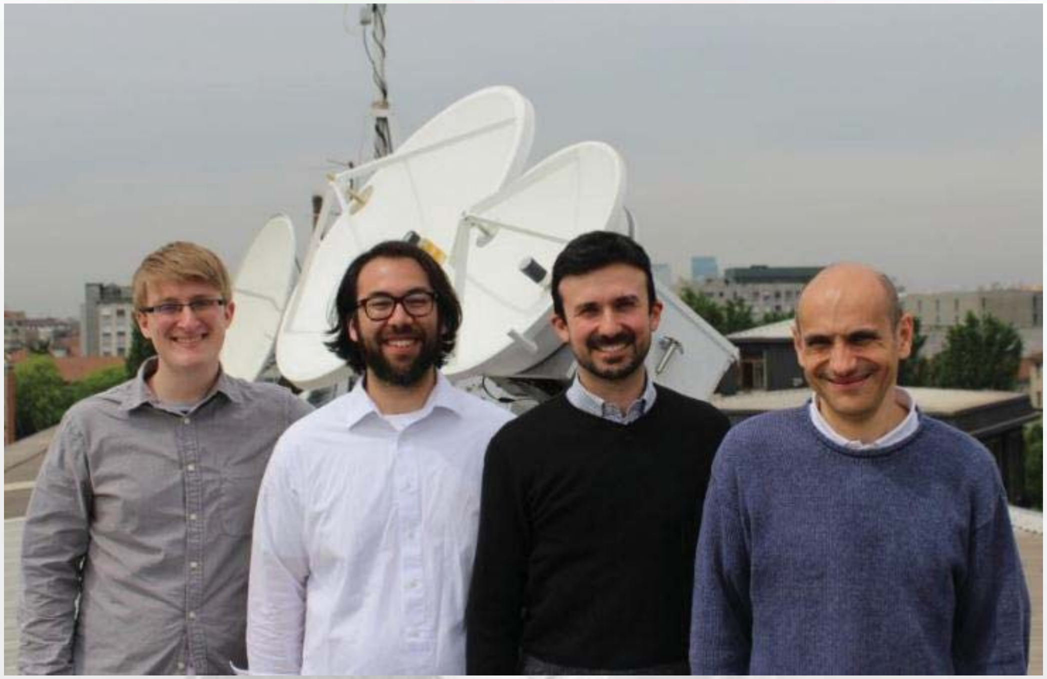


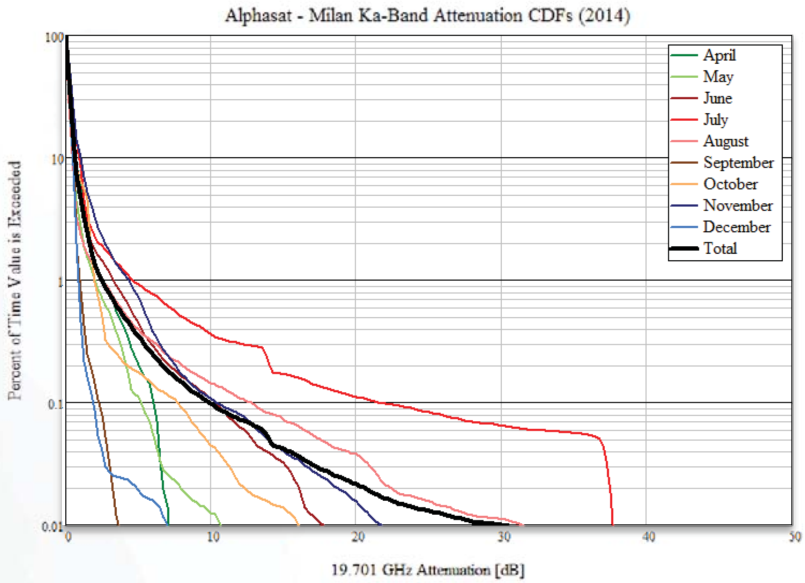
* *K. McCarthy, F. Stocklin, B. Geldzahler, D. Friedman, P. Celeste, "NASA's Evolution to Ka-band Space Communications for Near-Earth Spacecraft," AIAA SpaceOps 2010, Apr. 25-30, 2010, Huntsville, AL*

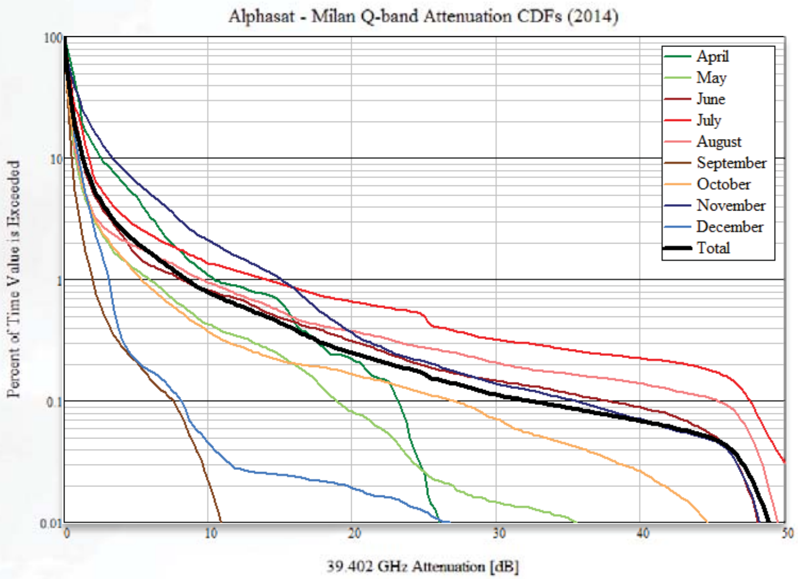
Collected 3+ years of low elevation angle gaseous absorption
Coordinating with ESA to install Ka-band (20.2 GHz) beacon receiver for rain attenuation/scintillation measurements

Alphasat Campaign

Propagation Studies in the Q-band







Instrument : K/Q-band Beacon Receiver (20/40 GHz)
Optical Disdrometer

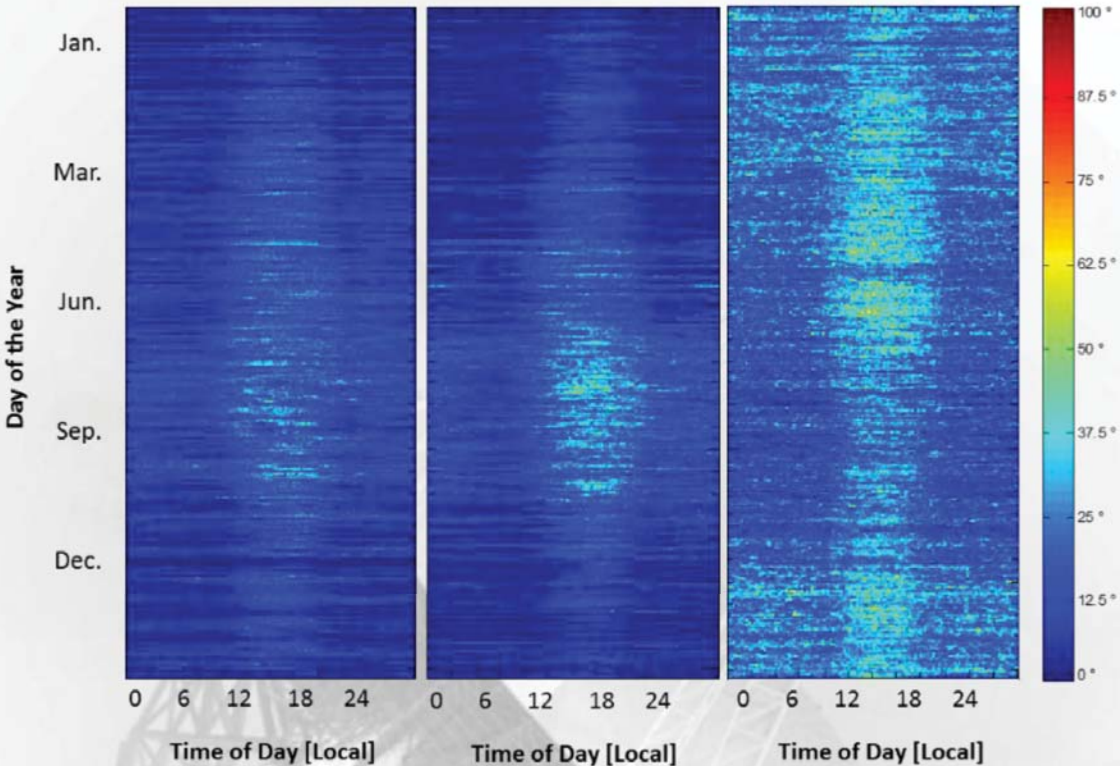
Data Collection Started : May 2014

Total Number of Months : 7 (0.6 Years)

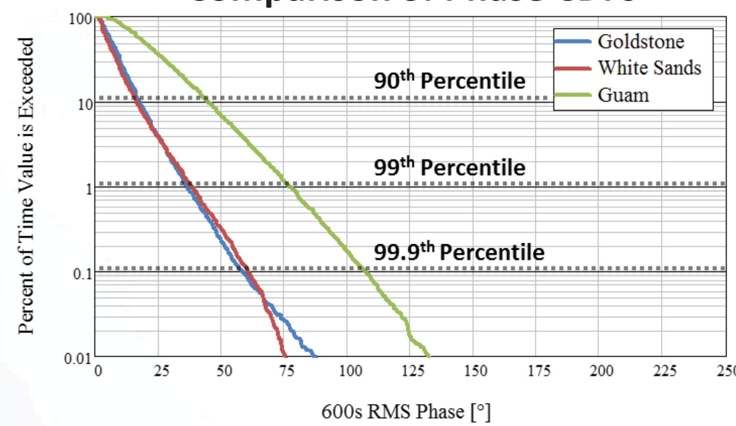
- First 40 GHz propagation data collected by NASA
- **GRC receiver recognized as highest-performing receiver of all Alphasat experimenters (>40 dB dynamic range)**
- **Collaboration with ASI for 20km site diversity measurements**

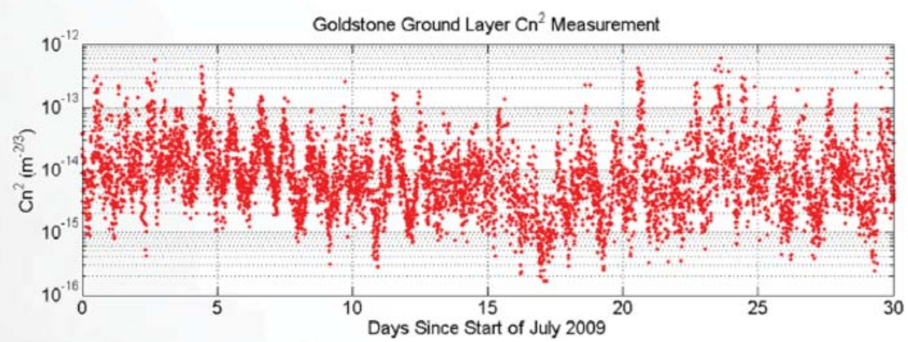
MODEL DEVELOPMENT

Atmospheric Microwave Phase Turbulence Modeling



Comparison of Phase CDFs





Model for Phase Turbulence Statistics (TBD):

$$\sigma_{\phi} = f(Nwet, v, \theta, v)$$

Derivation of Cn2 from Interferometric Measurements:

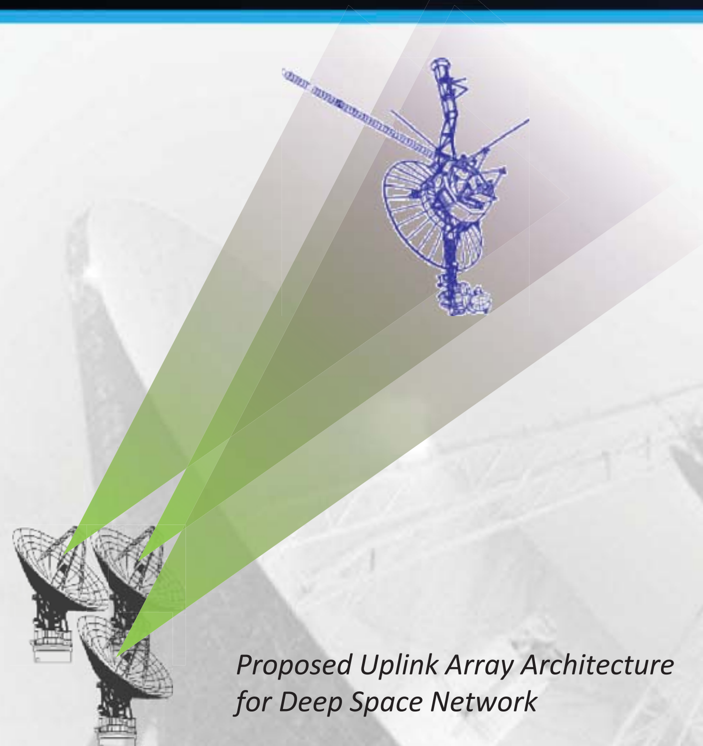
$$C_{\mathrm{n}}^{2} = 0.043 D_{\Delta \mathrm{H}}(\infty) \Lambda_{1}^{-1} d^{-\beta} H^{-1}$$

TABLE II
MEAN VALUES OF C_n^2 AT NASA GROUND SITES

Location	C_n^2 [2010-2012]	C_n^2 [June-Aug.]	C_n^2 [Dec.-Feb.]	C_n^2 99%
Goldstone, CA (DSN)	$2.04\text{x}10^{-14}$	$3.02\text{x}10^{-14}$	$8.45\text{x}10^{-15}$	$1.55\text{x}10^{-1}$[illegible]
White Sands, NM (SN)	$2.08\text{x}10^{-14}$	$4.40\text{x}10^{-14}$	$5.99\text{x}10^{-15}$	$2.85\text{x}10^{-1}$[illegible]
Guam (SN)	$9.8\text{x}10^{-13}$	$8.7\text{x}10^{-13}$	$1.1\text{x}10^{-12}$	$8.3\text{x}10^{-13}$

Atmospheric Phase Turbulence in an Array Environment

Deep Space Network (DSN)



Proposed Uplink Array Architecture for Deep Space Network

$$EIRP_{array} = \sum_{m=1}^{N} G_m \cdot \sum_{n=1}^{N} P_n$$

Assuming identical antenna elements,

$$EIRP_{array} = G_{array} \cdot NP_0$$

$$\langle G_{array} \rangle = \eta D_0 \frac{1}{N} \sum_{m=1}^{N} \sum_{n=1}^{N} e^{-\frac{\sigma_{mn}^2}{2}}$$

Propagation data characterizes this value (variance in phase amongst widely distributed antenna elements)

$$\sigma_{mn}^2(\theta_{el}, f, r) = \sigma_{mn}^2(\theta_0, f_0, r_0)\left(\frac{f}{f_0}\right)\left(\frac{r}{r_0}\right)^{\alpha}\left(\frac{\sin\theta_0}{\sin\theta_{el}}\right)$$

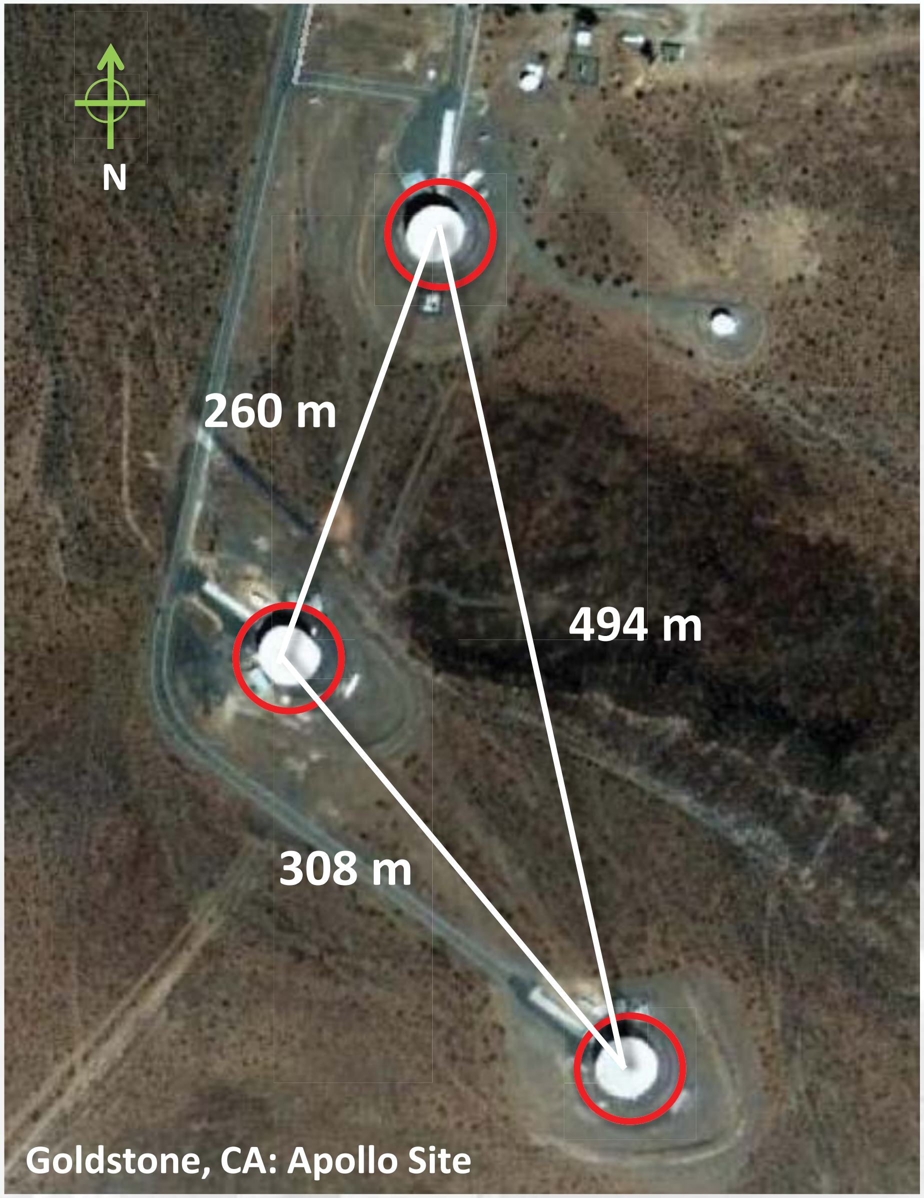
Concept

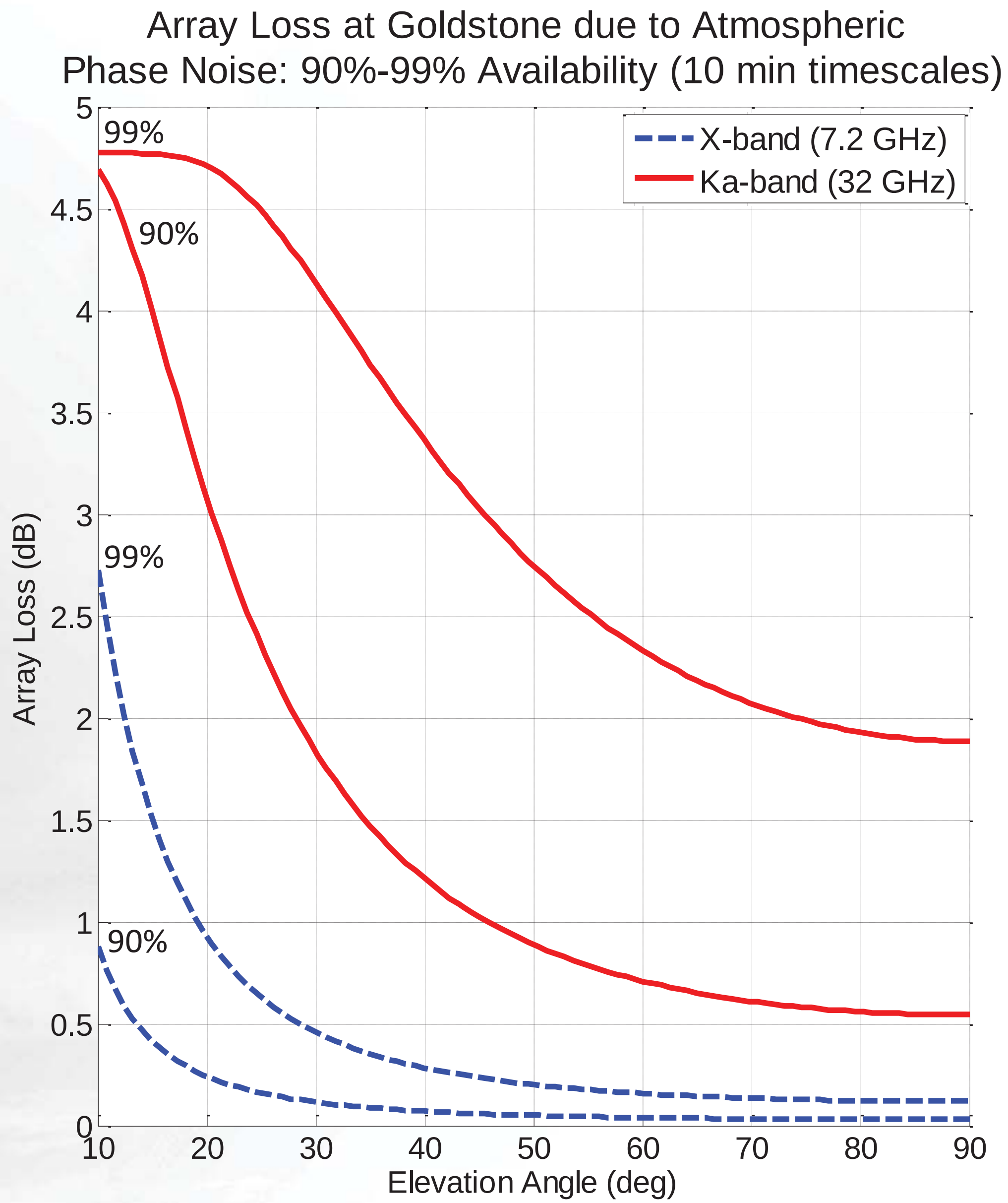
Arraying of several small aperture antennas vs. single large aperture antenna provides the following advantages:

- Reduced maintenance costs
- Graceful degradation of performance of communications system
- Relative ease of meeting strict surface accuracy requirements for small apertures
- Enable new communications capabilities
- N^2 improvement in Effective Isotropic Radiated Power (EIRP)

Atmospheric Phase Turbulence in an Array Environment

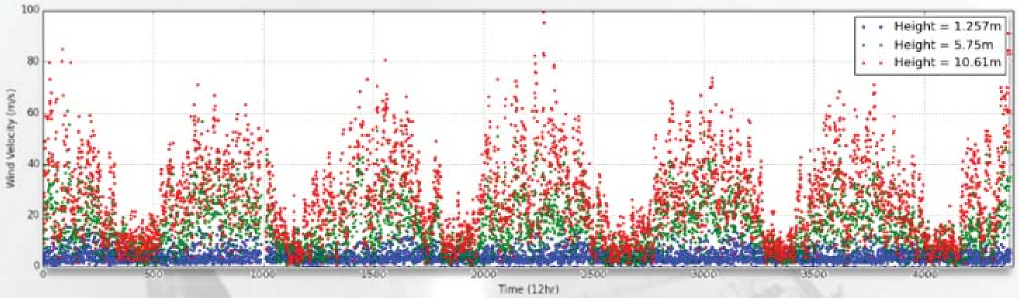
Deep Space Network (DSN)

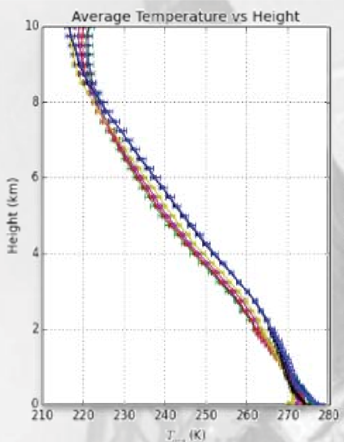


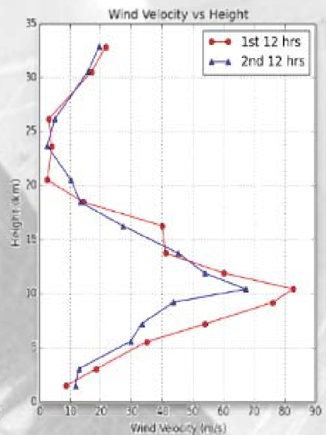


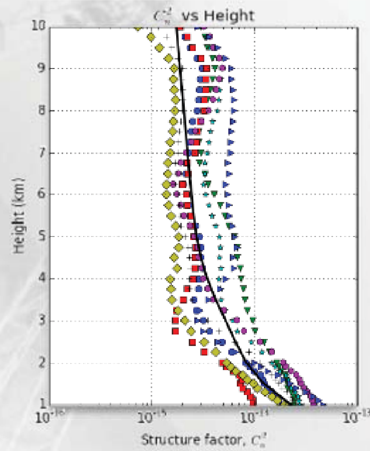
Atmospheric Optical Scintillation Modeling

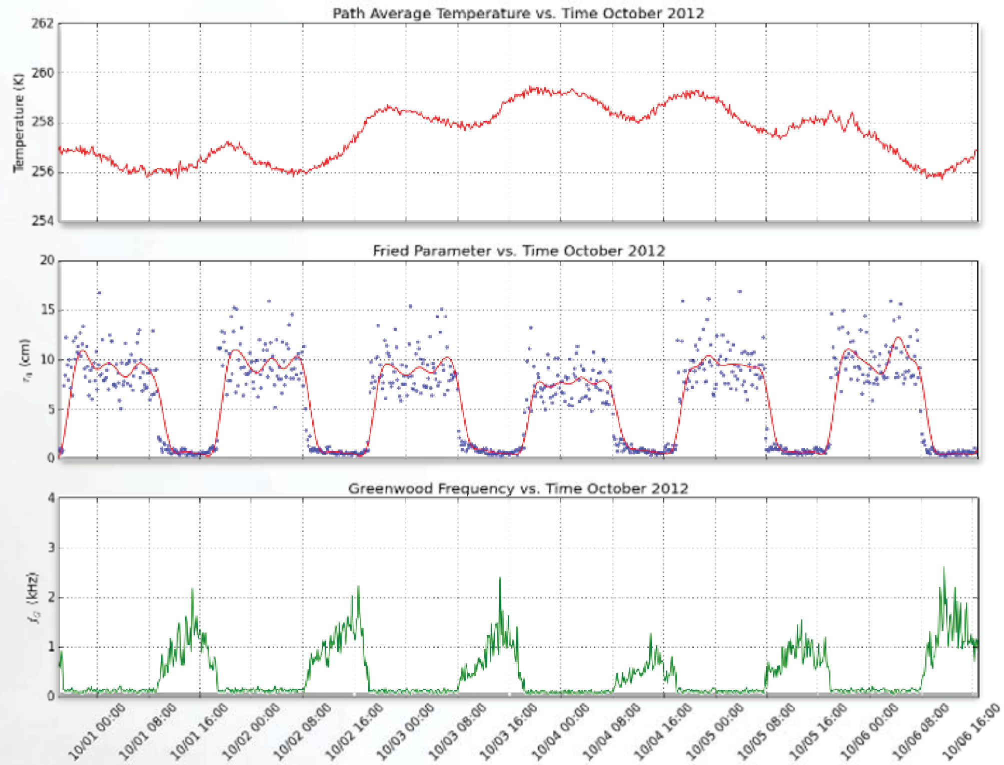
Preliminary Analysis of Optical Performance at White Sands











$$HV(h) = Ae^{-\frac{h}{H_A}} + Be^{-\frac{h}{H_B}} + Ch^{10}e^{-\frac{h}{H_C}} + De^{-\frac{(h-H_D)^2}{2d^2}}$$

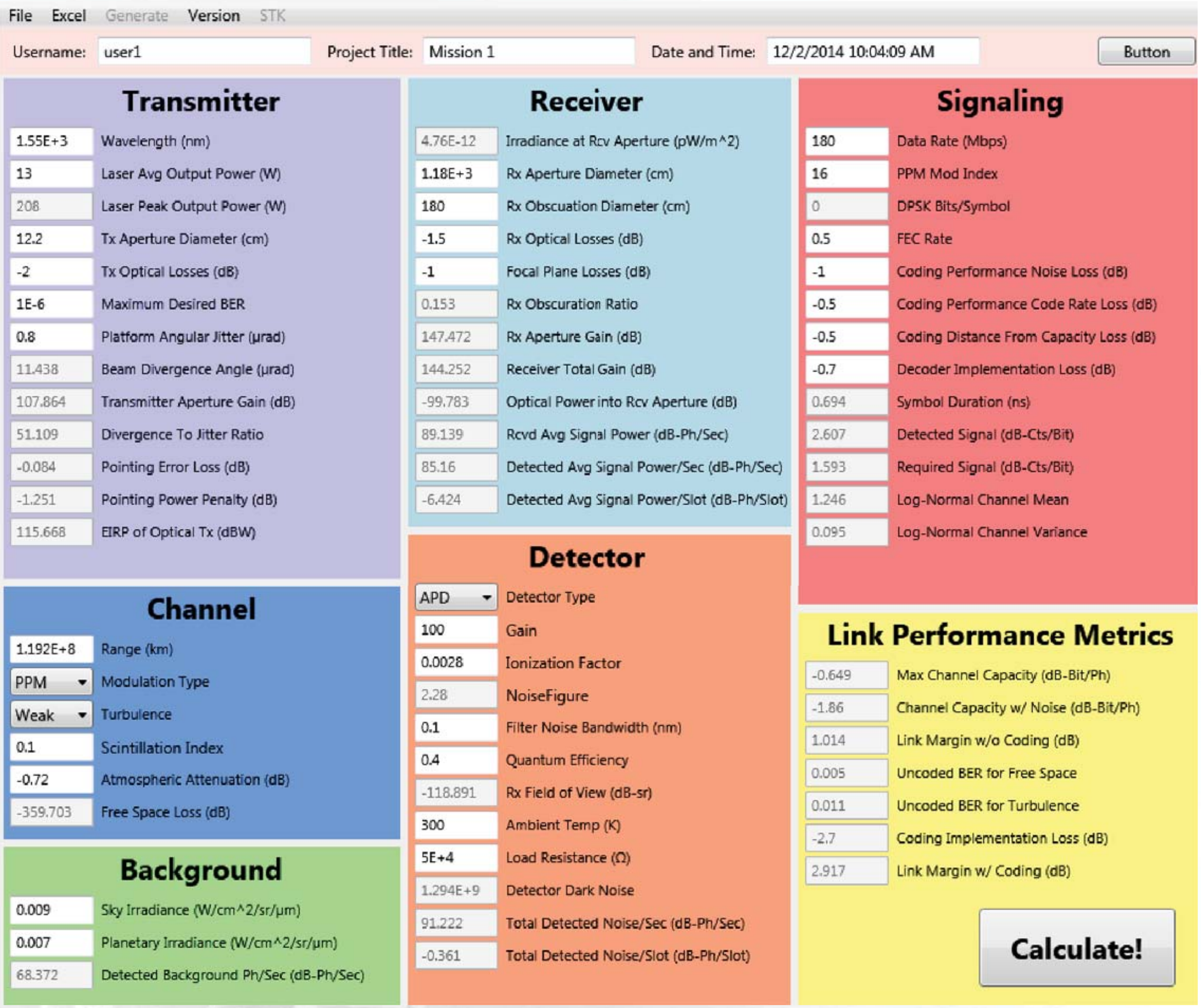
Coherence radius, $r_0 = 0.423\left(\frac{2\pi}{\lambda}\right)^2 \int C_n^2(h)dh,\ \lambda$ = 1550nm

Modified Structure Parameters:

$$C_T^2(T,U,\Delta t) = \frac{4\langle (T(r)-T(r+U\Delta t))^2\rangle}{k_U^{-2/3}\left[0.57722+\log(U\Delta t)+\frac{3}{2}\log\left(2k_U^{2/3}\right)+\frac{1}{2}\left(\frac{v}{U}\right)^2\right]}$$

$$C_n^2 = \left(\frac{77.689\,\langle P\rangle}{\langle T\rangle^2}\right)^2 C_T^2(T,U,\Delta t)$$

Optical Link Budget Analysis Tool



- **Rapid assessment of the operation of an optical communications link anywhere within the solar system as well as within GEO/LEO orbits**
- **Dynamic evaluation of optical link operation, accounting for the locations of deleterious noise sources with respect to the link and their impact on, e.g., achievable data rate during these periods**
- **Provides temporal and data rate connectivity throughout the lifetime of a mission yielding calculations for potential total data throughput of a mission**
- **Tool can be directly interfaced with the Satellite Tool Kit (STK) from which it gets its dynamic capability.**
- **Software configuration of tool allows extensive reporting capabilities as well as the flexibility to add as ‘modules’ new optical detector types, new modulations schemes, etc.**
- **Optical tool can be employed for the simulation of entire relay satellite system when used with an attendant tool for RF.**

PROPAGATION LABORATORIES

RF Propagation Laboratory

Bldg. 55 Rooftop radiometer testing

Bldg. 55 Propagation Laboratory used for component/system level testing and integration

NASA Ground Station (NGS) 5.5-m beam waveguide antenna for receiver system testing/check-out

Feed horn system upgrade completed to transition ground station for operation to Ka/Q/V/W bands

Millimeter Wave Laboratory

Bldg. 55 Millimeter Wave Laboratory for component/system level testing and integration

Presently transitioning test equipment to millimeter wave:

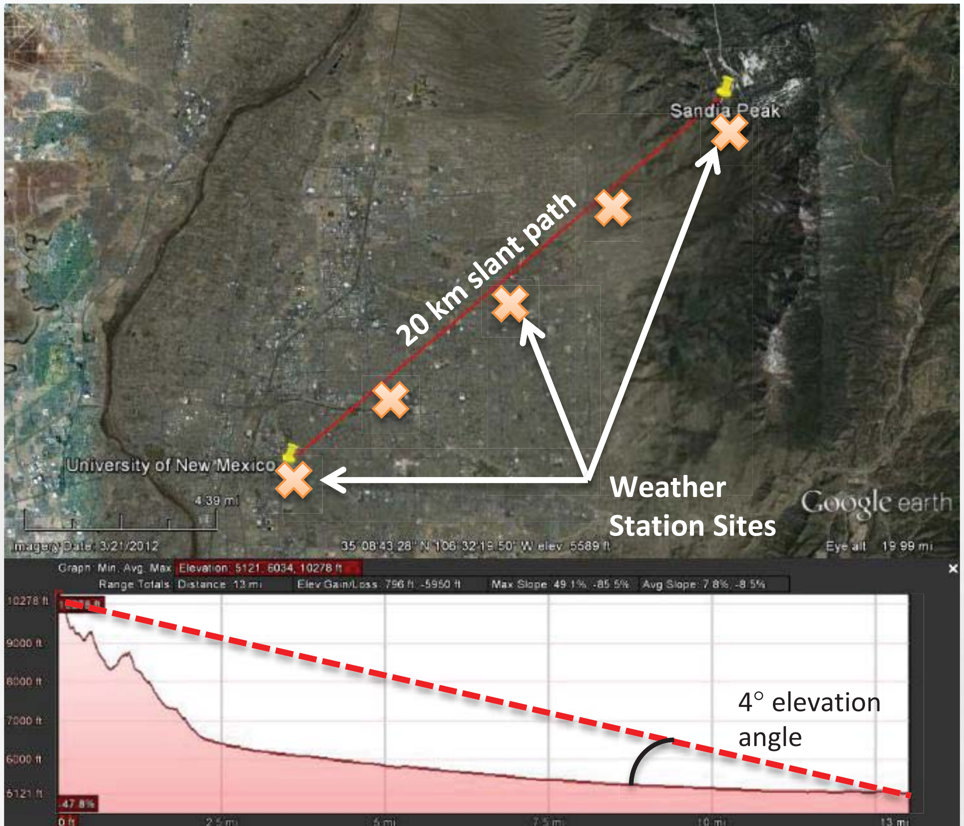
- Spectrum Analyzer
  (up to 90 GHz)
- Vector Network Analyzer
  (up to 110 GHz)
- Laboratory Investment Fund proposal in place to procure Signal Generator
  (up to 110 GHz)

FUTURE PLANS

Activities in the Millimeter Wave

AFRL Terrestrial Link Experiment (Summer 2015)

Propagation Models/Measurements in the V/W-band



Collaboration with AFRL and University of New Mexico (UNM) provides cost-effective opportunity to conduct immediate near-term rain fade and depolarization measurements prior to having an active W/V-band beacon for model validation and rain fade mitigation.

Measurement equipment to include:

- Beacon Transmitter on Sandia Peak (72/84 GHz)
- Beacon Receiver at UNM
- V/W-band Microwave Radiometer at UNM
- *Optical Transmitter/Receiver for concomitant measurements along path*
- Multiple Optical Disdrometers along path for rain drop size distribution measurements
- Multiple weather stations along path for path profiling information
- Super Doppler Radar for path profiling information

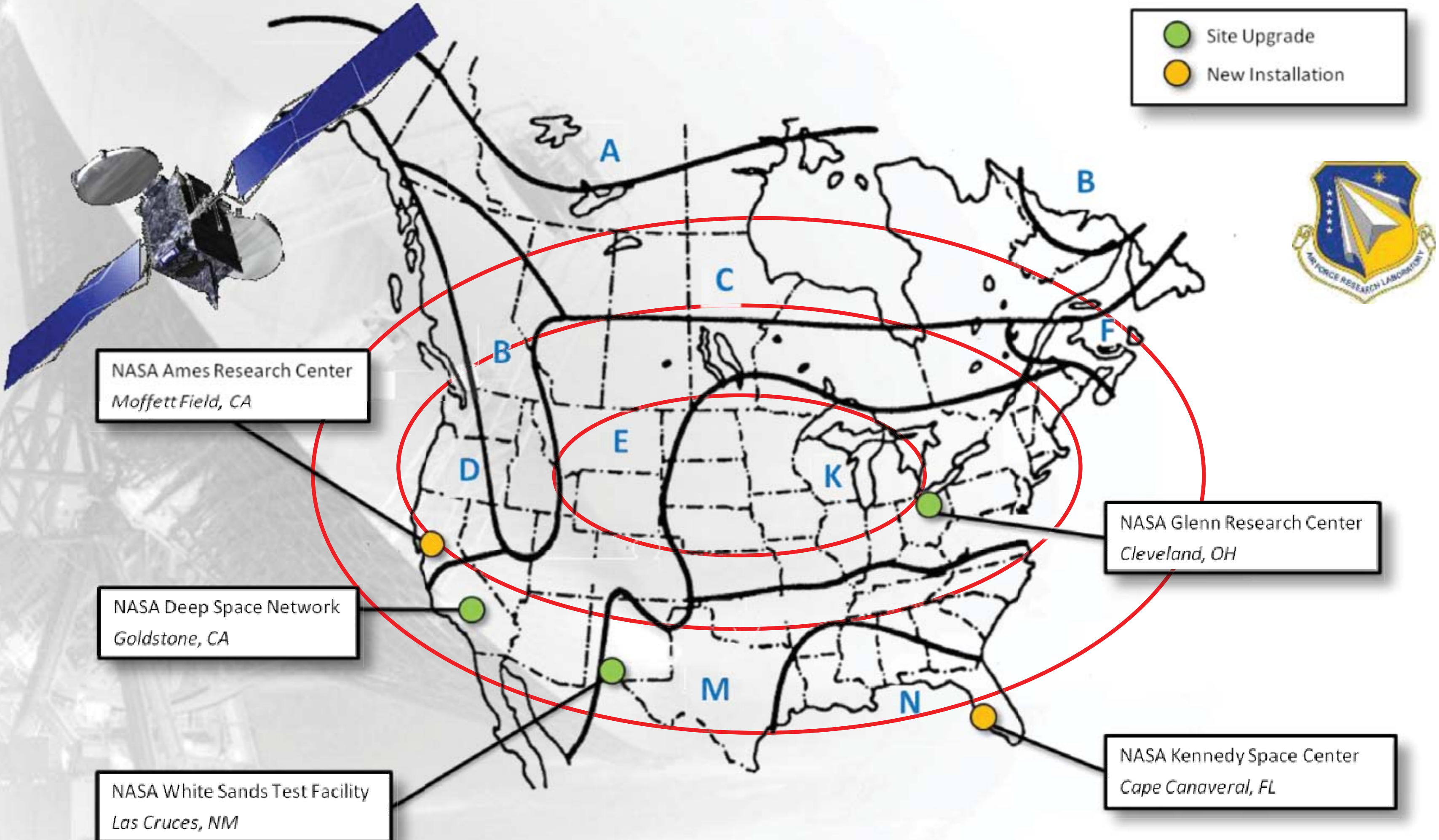
IMPACT:

- **Terrestrial Line-of-Sight Experiment in W/V-band will provide immediate preliminary validation/prediction of mm-wave rain attenuation and depolarization models prior to the expected W/V-band beacon payload launch in 2018 timeframe.**
- **Will provide a testbed for prototype propagation terminals to reduce experiment risk.**

W/V-band Satellite Communications Experiment

Opening the Millimeter Wave

- AFRL W/V-band Satellite Communications Experiment (WSCE)
  - Conduct ACTS-like CONUS propagation campaign at V/W bands
  - Expected payload launch date in 2018



THANK YOU!